A STANDARD METHOD TO CHARACTERIZE TEXTURE ATTRIBUTES OF FRESH AND PROCESSED FOODS

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

A Standard Method to Characterize Texture Attributes of Fresh and Processed Foods.
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This study focused on the development of a standard method for characterizing the texture attributes of fresh and processed foods. Currently, there is no standard method that can be used to determine textural attributes among a diversity of food products. The method developed will be based on the measurement of well-defined mechanical and rheological properties and should be reproducible, instrument-independent, and correlate well with sensory analyses. A variety of fresh and processed foods for which texture is critical to the quality of the food were tested. Two instruments were used in this study to determine the reproducibility of a standard method: a TA-TX2 Food Texture Analyzer (Texture Technologies, NY) and a Brookfield CT3 Texture Analyzer (Model CT3-100, Brookfield Engineering Laboratories, MA). A fresh food product (cherry tomato) and a processed food product (marshmallow) were selected for this study due to their well-defined geometric shapes and dimensions that reduced variability due to sample size variations. Compression, puncture, and Texture Profile Analysis (TPA) tests were performed to determine if the results were instrument-dependent. In the compression test, Young's modulus, yield strength, and ultimate strength were calculated for the marshmallows. All the food mechanical properties were not significantly different ($p<0.001$). In the puncture testing on the cherry tomatoes, Young's modulus, yield strength, and ultimate strength were also calculated

without significant differences ($p<1000$) between the instruments. A TPA test was run on both the marshmallows and cherry tomatoes and several textural properties were calculated from each force-time curve. For the marshmallows, $hardness_1$, $hardness_2$, and springiness were measured . When comparing the results between the TA-TX2 and Brookfield CT3, these properties were not significantly different ($p<0.001$). In the cherry tomato TPA testing, only $hardness_1$ and $hardness_2$ were calculated due to time constraints. Both $hardness_1$ and $hardness_2$ from both instruments were found to not be significantly different ($p<0.001$), but further testing is recommended to measure other textural properties using the TPA method. For compression, puncture, and TPA testing, it was proven that both instruments, the TA-TX2 and Brookfield CT3, will yield the same results. Users of textural instruments can rely upon data from either analyzer and trust that the results would not be significantly different.

DEDICATION

I would like to dedicate this thesis to my parents for always believing in me and encouraging me to follow my dreams.

ACKNOWLEDGMENTS

I would like to thank Dr. Elena Castell-Perez for being my research advisor and guiding me along this process. She has been extremely supportive throughout the past year, and I am thankful that she gave me this opportunity to work in her lab. I have immensely strengthened my knowledge in food science through this experience and it would not have been possible without Dr. Castell.

CHAPTER I

INTRODUCTION

Texture attributes of fresh and processed foods are key in the assessment of product quality and acceptability. For instance, crispness and crunchiness of potato chips and celery are critical to their overall quality, and the processing industry has dedicated a great deal of effort to measure these attributes. This means that in many cases, food texture is even more important than taste or appearance. Hence, evaluating the textural attributes of food products is crucial to both quality and consistency among products. These attributes are evaluated by subjective or objective methods. Empirical methods have been widely implemented by the food industry because they are relatively fast, inexpensive, and correlate well with the assessment of organoleptic attributes using sensory analysis (Chen and Opara, 2013). However, the parameters measured from these tests are poorly defined, are instrument-dependent, and there is lack of an absolute standard (Bourne, 2002). Besides, the vast diversity of food products creates a challenge in selecting the appropriate method for textural characterization.

One method widely applied in the food industry is the Texture Profile Analysis (TPA), designed to imitate the chewing action of the teeth (Szczesniak, 2002). Although this test has good correlation with sensory analysis, it is imitative in nature and comparability of results with other methods is lacking.

The engineering approach consists in performing stress-strain tests and determining well-defined mechanical properties such as stiffness, firmness, hardness, and yield (Steffe, 2006). These objective tests may also provide information about molecular structure and effects of processing. However, these properties may have a different meaning when relating them to what is sensed by the person when eating or touching the food. Consequently, although a lot of effort has been invested in improving the objective measurement of textural attributes of fresh and processed foods, there is still need for a standard method with the following characteristics: (a) simple to perform; (b) rapid; (c) suitable for routine work; (d) good correlation with sensory data; (e) closely duplicates mastication; (f) complete texture measurement; (g) must know what is measured; (h) can use large and small size samples (Bourne, 2002), and (i) is instrument-independent.

This research will address the latter characteristic of standard (objective) texture measurement tests. These objective tests are performed using “texture analyzers” which are instruments used to deform a food sample by pressing, pulling, piercing, squashing, twisting and/or crushing it to measure food texture in a scientific way that can be repeated to give standardized assessment methods (IFT 2013). However, there are several types of these machines available with different attachments to deform the test samples and no correlation has been established among them, which creates a serious problem to the food scientist or engineer who relies on their results to make decisions regarding the choice of ingredients to achieve a particular texture or process design parameters. In addition, these texture-testing instruments can detect and quantify only certain physical parameters, which then must be interpreted in terms of sensory perception (Szczesniak, 2002).

Based on the problem stated above, I plan to answer the following questions: Will different machines yield the same results regarding the textural attributes of a variety of foods? On the other hand, will the results be dependent on the type of instrument used? If the answer to the latter question is "Yes," can I develop a standard, reproducible, instrument-independent method to characterize the texture attributes of selected fresh and processed foods, based on measurement of well-defined mechanical and properties of the food, which correlate well with sensory analyses? The reproducibility of the method will be assessed using two commercially available instruments. Correlation among the parameters obtained using the methods outlined above will be established. Those parameters that correlate poorly will be eliminated or other methods will be attempted. Those parameters that correlate well will be identified for future correlation with sensory analysis. No human subjects will be used in this study.

CHAPTER II

MATERIALS AND METHODS

Description of instruments

Two instruments commonly used in the food industry, the TA-TX2 Texture Analyzer (Texture Technologies, NY) and the Brookfield CT3 (Brookfield Engineering Laboratories, MA), were used to determine whether results obtained from both units were equivalent. These instruments essentially have the same functionality, but there are differences between the two texture analyzers, for instance, the Brookfield CT3 is newer than the TA-TX2 and therefore the interface for the software is updated and modern. Both instruments have a maximum load cell of 50kg, but the Brookfield CT3 has a wider range of load cell options than the TA-TX2. A limitation of the Brookfield CT3 is that the probe only has a 0.10m travel range, limiting the types of testing that can be done on this instrument.

Description of foods used

The two instruments were tested with marshmallows and cherry tomatoes. These food products were selected as one being fresh (cherry tomato) and one being processed (marshmallow), and both have very well defined geometric shapes and dimensions that reduced variability due to sample size variations. A package of regular marshmallows and cherry tomatoes were randomly selected and purchased from the local grocery store. Twenty marshmallows and twenty cherry tomatoes were randomly selected and each divided into two groups of ten on the day of the experiment. Using a digital caliper, the height (mm) and diameter (mm) of the marshmallows and cherry tomatoes was measured.

Description of methods

This study focused on compression, puncture, and TPA testing using both instruments. There are two types of compression tests: uniaxial and bulk. A uniaxial test is where the sample is compressed in one direction and is unrestrained in the other two dimensions, whereas in a bulk compression test, the sample is compressed in three dimensions (Bourne, 2002). In this study, a uniaxial compression test was used on both the marshmallows and cherry tomatoes. Compression testing measures the firmness or hardness, of a food product and creates an averaging effect due to its larger surface area for testing (Texture Technologies, NY). Penetration, or puncture testing, measures the force required to push a probe into a food product (Bourne, 2002). Penetration is commonly used for objects that may not be repeatable in size and shape, but have a repeatable feature in which the probe can be applied. TPA consists of compressing a food product twice to replicate the action of mastication. Data from a TPA test is arranged into a force-time curve where a variety of textural properties can be measured that will correlate to sensory evaluation (Bourne, 2002).

TA-TX2 Texture Analyzer compression test parameters

This test was performed on 10 marshmallows. The instrument was set to a Pre-Speed of 1 mm/s, Test-Speed of 1 mm/s, and Post-Speed of 10 mm/s. The distance was set to 50% strain, the trigger box at .049 N, and the acquisition rate to 50 points per second (pps). A 75mm diameter compression plate performed the compression onto the marshmallow and was calibrated by the TA-TX2 Analyzer before testing began. The compression test was run once per marshmallow for a completion of 10 total trials. Prior to testing, the height (mm) and diameter (mm) was measured and recorded for each marshmallow. Experiments were run with samples at room temperature.

Brookfield CT3 Texture Analyzer compression test parameters

This test was run on the remaining 10 marshmallows. Similar to the TA-TX2 Texture Analyzer, the Brookfield CT3 Analyzer was set to a Pre-Speed of 1 mm/s, Test-Speed of 1 mm/s, and Post-Speed of 10 mm/s. The distance was set to 50% strain, the trigger box at .049 N, and the acquisition rate to 50 pps. A 75mm diameter compression plate performed the compression test and was calibrated by the Brookfield CT3 Texture Analyzer before testing began. The compression test was run once per marshmallow for a completion of 10 total trials. Prior to testing, the height (mm) and diameter (mm) was measured and recorded for each marshmallow. Experiments were also run with samples at room temperature.

TA-TX2 Texture Analyzer TPA parameters

This test was run on 10 marshmallows and the instrument was set to a pretest speed of 1 mm/s, a test speed of 1 mm/s, and a return speed of 1 mm/s. The data rate was set to 50 pps, the test ran 2 cycles, and a trigger load of 0.07 N was used. The target was set to 75% deformation and the hold time was 0 seconds. A 75mm diameter compression plate performed the TPA test and was calibrated by the TA-TX2 Texture Analyzer before testing began. The TPA was run once for each marshmallow for a total of 10 tests. Prior to testing, the height (mm) and diameter (mm) was measured and recorded for each marshmallow. Experiments were run with samples at room temperature.

Brookfield CT3 Texture Analyzer TPA parameters

This test was also performed on 10 marshmallows. The analyzer was set to a pretest speed of 1 mm/s, a test speed of 1 mm/s, and a return speed of 1 mm/s. The TPA test ran two cycles, has a data rate of 50 point/s, and a trigger load of 0.07N. The target was set to 75% deformation and the hold time was 0 seconds. A 75mm diameter compression plate performed the TPA test and was calibrated by the Brookfield CT3 Texture Analyzer before testing began. The TPA was on each marshmallow once for a total of 10 tests. Prior to testing, the height (mm) and diameter (mm) was measured and recorded for each marshmallow. Experiments were also run with samples at room temperature.

TA-TX2 Texture Analyzer puncture test parameters

This test was performed on the randomly selected first group of 10 cherry tomatoes. Each test was completed with a 2 mm diameter puncture probe that was calibrated by the TA-TX2 Texture Analyzer before testing. The parameters for the testing included a Pre-Speed of 1 mm/s, Test Speed of 1 mm/s, and Post-Speed of 10 mm/s. The distance was set at 10% strain, a trigger point at .049 N, and an acquisition rate at 50 pps. The puncture test was run once for each cherry tomato for a total of ten trials. Before testing began, the height (mm) and diameter (mm) of each cherry tomato was measured and recorded. Experiments were run with samples at room temperature.

Brookfield CT3 Texture Analyzer puncture test parameters

This test was performed on the second group of 10 cherry tomatoes. The testing was completed with a 2 mm diameter puncture probe that was calibrated by the Brookfield CT3 Texture Analyzer before testing. The parameters for the testing were set at a Pre-Speed of 1 mm/s, Test Speed of 1 mm/s, and Post-Speed of 10 mm/s. The distance was set at 10% strain, a trigger point at .049 N, and an acquisition rate at 50 pps. The puncture test was run once for each cherry tomato for a total of ten trials. Prior to testing, the height (mm) and diameter (mm) of each cherry tomato was measured and recorded. Experiments were run with samples at room temperature.

Data collection for compression and puncture tests

For both the compression and puncture tests, force-distance data was collected from the analyzers. For each of the test, average values of force and distance among the ten trials were calculated. From the data, a force-distance curve was created for each test. Young's modulus (in MPa) was calculated from the slope of the linear region of the force-distance curve (Figure 1). Hooke's law was valid in calculating Young's modulus for each test by dividing stress over strain within the linear region, which equates to E, Young's modulus, or the stiffness of the product. Yield Strength (in MPa) was calculated by determining the stress at the point in which the force-distance curve becomes non-linear and the product yields, thus representing the hardness of the product (Figure 1). The ultimate strength (in MPa) was determined by finding the maximum peak of the linear region of the force-distance curve, which represents maximum stress, or strength of the product (Figure 1). The values of the properties obtained from the marshmallows and cherry tomatoes using both instruments were compared using an ANOVA test on JMP statistics software to determine whether the properties are instrument-dependent.

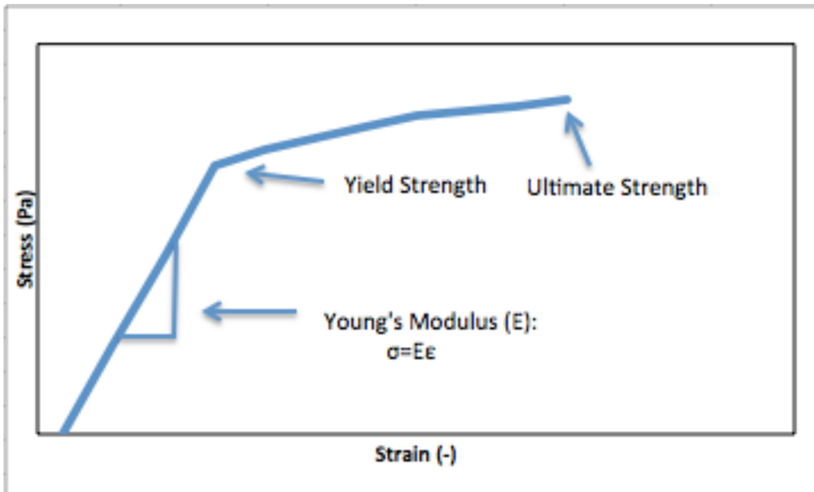

Figure 1: Force-distance curve highlighting the Young's modulus, yield strength, and ultimate strength properties of a material.

Data collection for TPA tests

Force, distance, and time data were collected for each of the four tests. From the data, force-time curves were created to determine the different textural properties of the marshmallows and cherry tomatoes. Through the analysis of a force-time curve, numerous textural properties can be calculated for a food product. For both the marshmallow and cherry tomato testing, the hardness_1 and hardness_2 values were calculated. The $\underline{\text{hardness}_1}$ value is the peak force on the first compression cycle, while $\underline{\text{hardness}_2}$ represents the peak force from the second compression cycle. Additionally, because marshmallows have high elasticity, the <u>springiness</u> of the marshmallow was calculated to determine how well the marshmallow springs back after the 75% deformation during the first compression cycle. The springiness is calculated by dividing length 2 by length 1 (Figure 2) . The values of the properties obtained from the marshmallow and cherry tomato tests using each instrument were analyzed using an ANOVA test on JMP statistics software to determine whether the properties are instrument-dependent.

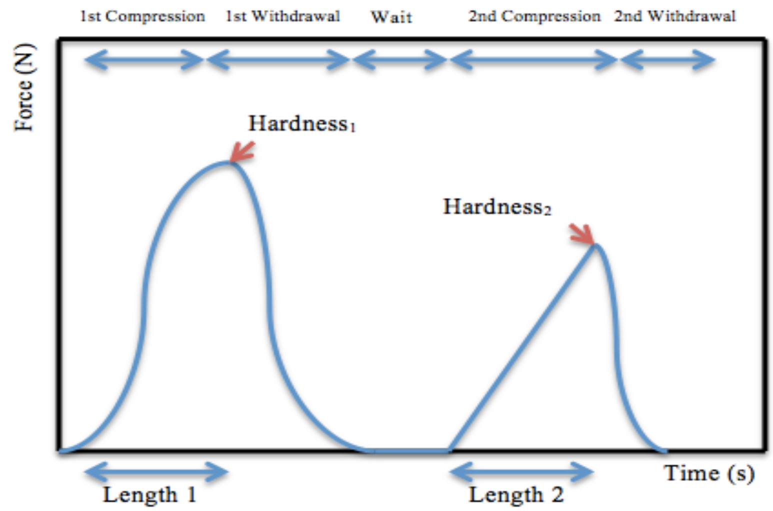

Figure 2: TPA force-time curve displaying calculations for hardness and springiness of a material.

CHAPTER III

RESULTS

Marshmallow compression test

Three material properties, Young's modulus, yield strength, and ultimate strength values were calculated using the stress-strain curves (Figures 2 and 4). The mean Young's modulus for the marshmallow compression test on the TA-TX2 Texture Analyzer was 0.017 MPa +/- 0.001 (Table 1). The mean Young's modulus obtained using the Brookfield CT3 was 0.018 MPa +/- 0.000. Results from both texture analyzers indicate that marshmallow has a low Young's modulus value, meaning that the marshmallow is not very stiff, but instead a softer and more flexible material. Statistical analysis suggests that the Young's modulus from both measuring units were not significantly different ($p<0.0001$) (Table 1). Therefore, performing a compression test on marshmallow with both texture analyzers yielded statistically similar results. The yield strength was undetectable for both instruments, a result typical of soft and flexible materials like marshmallow. The mean ultimate strength obtained with the TA-TX2 Texture Analyzer was 0.0128 MPa +/- 0.000 while that obtained with the Brookfield CT3 Texture Analyzer was 0.0199 MPa +/- 0.000. Both values are low, indicating that a low amount of stress is needed to permanently deform the marshmallow. Statistical software has determined that the ultimate strength values from each texture analyzer are not significantly different ($p<0.001$). The low standard deviation values indicate the good reproducibility of the measurements for both instruments.

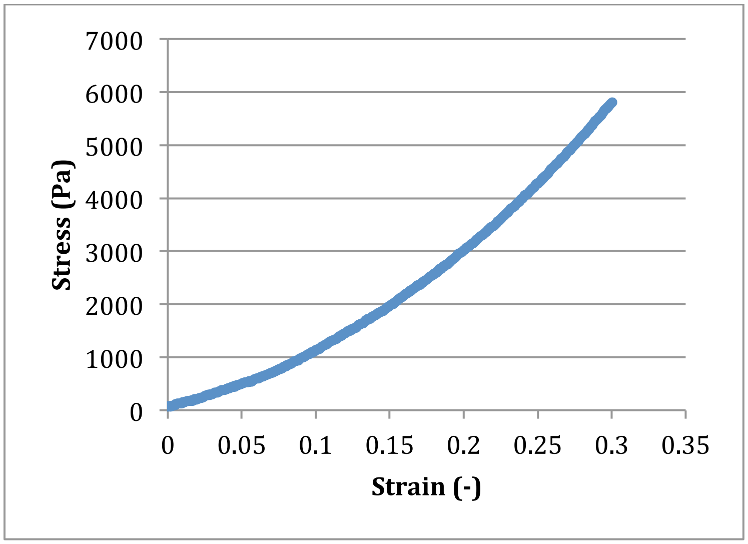

Figure 3: Stress-strain curve for marshmallow under uniaxial compression using the TA-TX2 Texture Analyzer

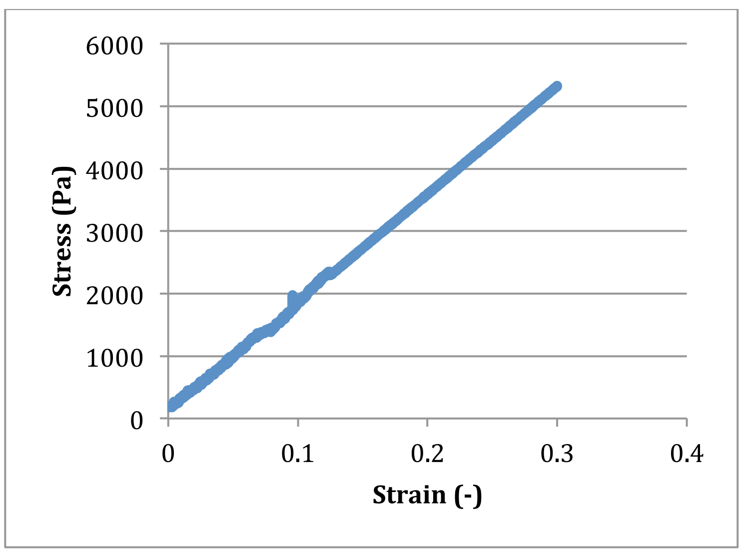

Figure 4: Stress-strain curve for marshmallow under uniaxial compression using the Brookfield CT3 texture Analyzer.

Table 1: Marshmallow compression test properties

	Property		
	Young's modulus (MPa)	Yield Strength (MPa)	Ultimate Strength (MPa)
TA-TX2	0.017 [a] +/- 0.001	---	0.0128 [a] +/- 0.000
Brookfield CT3	0.018 [a] +/- 0.000	---	0.0199 [a] +/- 0.000

[a]: : Means within a column, which are not significantly different (P<0.0001).

Cherry tomato puncture test

Three material properties, Young's modulus, yield strength, and ultimate strength of cherry tomatoes obtained from a puncture tests were calculated by using the stress-strain curves (Figures 5 and 6). The mean Young's modulus for the cherry tomato compression test on the TA-TX2 Texture Analyzer was 0.084 MPa +/- 0.0001 (Table 2). The mean Young's modulus obtained using the Brookfield CT3 was 0.067 MPa +/- 0.0006. Results from both instruments indicate that the cherry tomato has a low Young's modulus when compared to a range of different food products, meaning that cherry tomatoes are not very stiff. Statistical analysis suggests that the Young's moduli calculated from both measuring units were not significantly different ($p<0.0001$). The yield strength for the compression test on the TA-TX2 Texture Analyzer was 0.0058 +/- 0.0001 MPa and the yield strength on the Brookfield CT3 Texture Analyzer was 0.0050 MPa +/- 0.0003. The yield strength values represent the minimum stress needed for flow to begin in the cherry tomato. Because the outer skin of a tomato is easily punctured, low yield strength is achieves the flow of liquids outwards from inside the cherry tomato. Statistical analysis suggests that the yield strength values calculated from each instrument are not significantly different ($p<0.001$). The mean ultimate strength for the compression test on the TA-TX2 was 0.0122 MPa +/- 0.0000, while that obtained with the

Brookfield CT3 Analyzer was 0.0122 +/- 0.0001. The ultimate strength represents the maximum stress placed on a cherry tomato before it ruptures and are not significantly different (p<0.001) from one another.

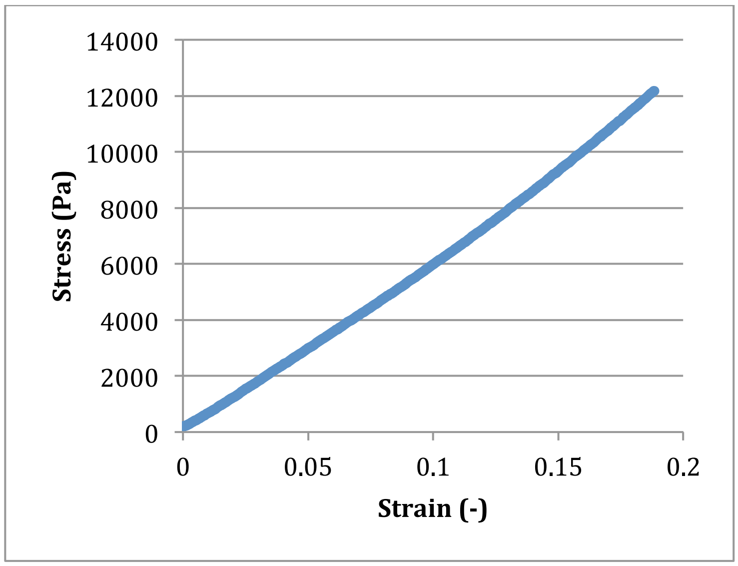

Figure 5: Stress-strain curve for cherry tomato under puncture testing using the TA-TX2.

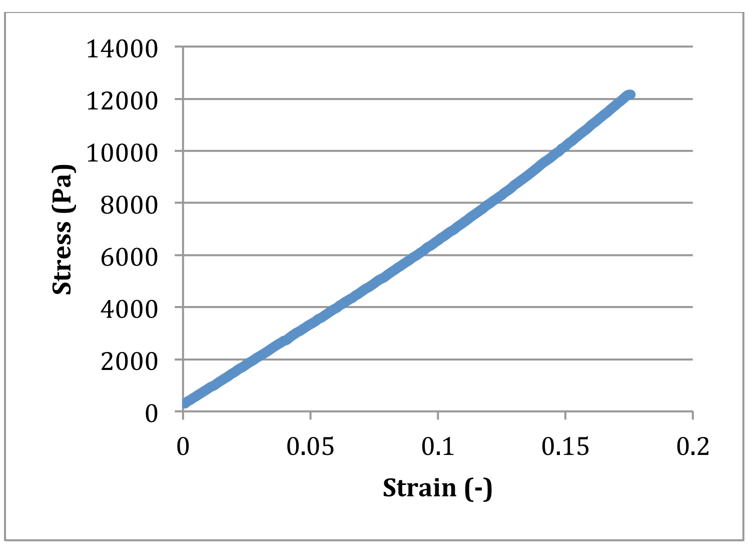

Figure 6: Stress-strain curve for cherry tomato under puncture testing using the Brookfield CT3.

Table 2: Cherry tomato puncture test properties.

	Property		
	Young's modulus (MPa)	Yield Strength (MPa)	Ultimate Strength (MPa)
TA-TX2	0.084 [a] +/- 0.0001	0.0058 [a] +/- 0.0001	0.0122[a] +/- 0.0000
Brookfield CT3	0.067 [a] +/- 0.0006	0.0050 [a] +/- 0.0003	0.0122 [a] +/- 0.0001

[a]: : Means within a column, which are not significantly different ($P<0.0001$).

Marshmallow TPA test

Hardness$_1$, hardness$_2$, and springiness were calculated from the TPA force-time curve (Figures 7 and 8). Using the TA-TX2 unit, marshmallow hardness$_1$ was 49.95 N +/- 0.206 and hardness$_2$ was 39.58 N +/- 0.122 (Table 3). Using the Brookfield CT3 unit, these values were 45.72 N +/- 0.041 and 39.74 N +/- 0.094, respectively. These values of hardness represents the maximum force (in N) of the first and second compression, respectively. The marshmallow's hardness values are classified as soft but firm, which directly correlates to the mastication of a marshmallow. These results also correlate well with the objective measurements of Young's modulus (stiffness) and ultimate strength obtained from the uniaxial compression test. Through statistical analysis, it was determined that both hardness$_1$ and hardness$_2$ are not statistically significant when comparing the results from both texture analyzers. The springiness of the marshmallow was 0.0006405 m +/- 0.097 on the TA-TX2 and 0.0006833 m +/- 0.054 on the Brookfield CT3. Springiness measures how much the marshmallow springs back after the first compression and because marshmallows are highly elastic, the springiness value is high relative to other food products. Statistical software also determined that the springiness values of the marshmallow TPA test on both analyzers were not statistically significant. As a result, both the

TA-TX2 and Brookfield CT3 will yield the same results when testing for $hardness_1$, $hardness_2$, and springiness using TPA.

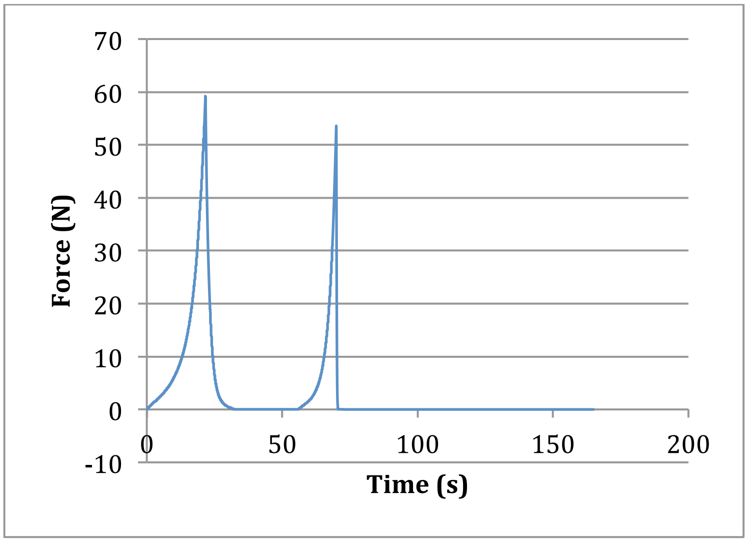

Figure 7: TPA of marshmallow on TA-TX2.

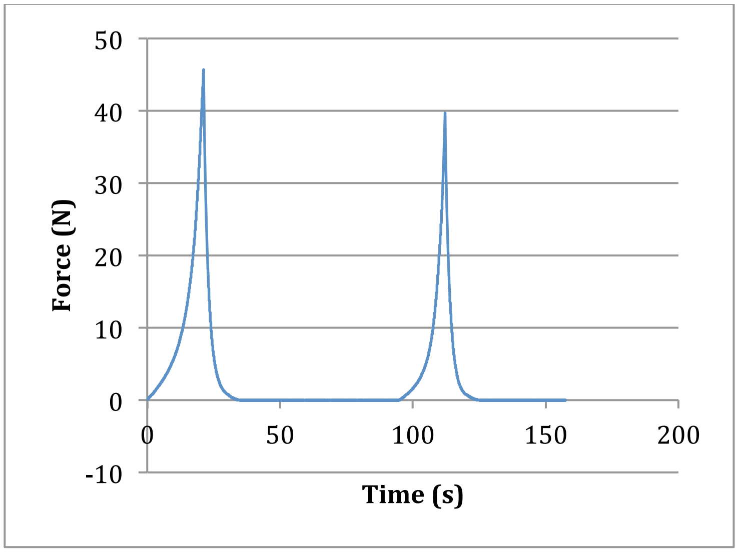

Figure 8: TPA of marshmallow on Brookfield CT3.

Table 3: Marshmallow TPA properties.

	Property		
	Hardness$_1$ (N)	Hardness$_2$ (N)	Springiness (m)
TA-TX2	49.95 [a] +/- 0.206	39.58 [a] +/- 0.122	0.0006405 [a] +/- 0.097
Brookfield CT3	45.72[a] +/- 0.041	39.74[a] +/- 0.094	0.0006833 [a] +/- 0.054

[a]: : Means within a column, which are not significantly different (P<0.0001).

Cherry tomato TPA test

Similarly, Hardness$_1$ and hardness$_2$ were calculated based on the TPA force-time (Figures 9 and 10). Using the TA-TX2 unit, the cherry tomato hardness$_1$ on the TA-TX2 was 3.774 N +/- 0.023 and hardness$_2$ was 1.676 N +/- 0.073 (Table 4). Using the Brookfield CT3 unit, these values were 3.620 N +/- 0.027 and 2.020 N +/- 0.089 respectively. Both the hardness$_1$ and hardness$_2$ values are low and correspond to the softness and ease of biting into a cherry tomato. These results also correlate well with the objective measurements of Young's modulus and ultimate strength obtained from the puncture test. Statistical software also found the hardness$_2$ values to not be statistically significant meaning that when testing both hardness$_1$ and hardness$_2$ on cherry tomatoes using TPA, the TA-TX2 and Brookfield CT3 will yield the same results. Tomato samples did not show any springiness.

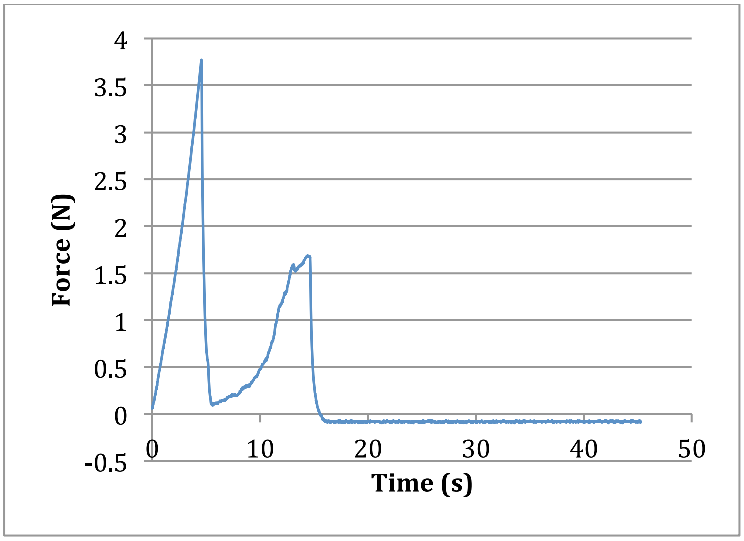

Figure 9: TPA of cherry tomato on TA-TX2.

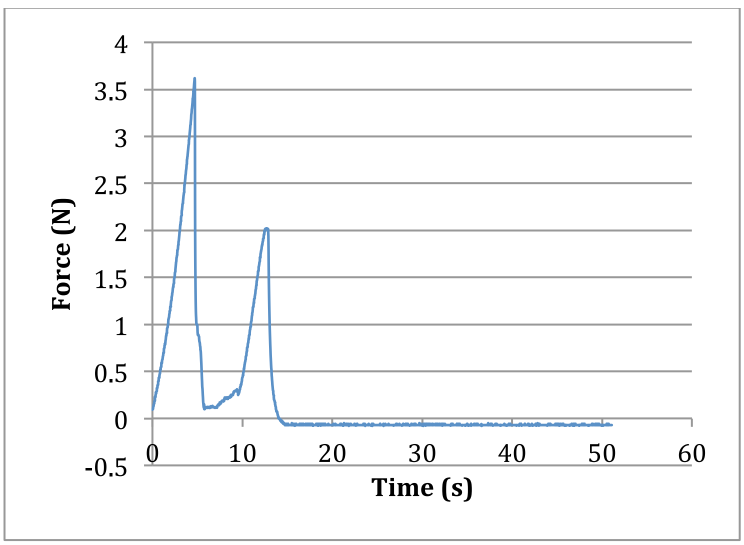

Figure 10: TPA analysis of cherry tomato on Brookfield CT3.

Table 4: Cherry tomato TPA properties.

	Property	
	Hardness$_1$ (N)	Hardness$_2$ (N)
TA-TX2	3.774 [a] +/- 0.023	1.676 [a] +/- 0.073
Brookfield CT3	3.620 [a] +/- 0.027	2.020 [a] +/- 0.089

[a]: : Means within a column, which are not significantly different (P<0.0001).

CHAPTER IV

CONCLUSION

Each of the three tests completed on both the TA-TX2 and Brookfield CT3 in this study resulted in material properties that were not significantly different ($p < 0.0001$) from one another. Young's modulus, yield strength, and ultimate strength obtained from the uniaxial compression test on marshmallow were similar ($p<0.0001$) for both texture analyzers. These properties represent the stiffness, hardness, and maximum strength of the food product, respectively. The same properties were calculated for the cherry tomato using puncture testing and were also found not significantly different ($p<0.0001$). In the TPA testing, $hardness_1$ and $hardness_2$, were measured for both the marshmallows and cherry tomatoes, while springiness was also measured in the marshmallows. These properties relate to the mastication of both food products and were found to have yielded the same results for both the TA-TX2 and Brookfield CT3 analyzer. Due to time constraints, the data on the cherry tomato TPA testing is incomplete and additional properties should be tested to determine statistical significance.

In conclusion, compression, puncture, and TPA testing on both marshmallows and cherry tomatoes have shown that the when using either the TA-TX2 and or the Brookfield CT3 should yield the same results. These new knowledge that the two texture analyzers will yield the same results is very valuable the food industry.. Users of textural instruments can rely upon data from either analyzer and trust that the results would be the same on both machines.

Because this study only focused on compression, puncture, and TPA testing, there is a need for further testing to determine whether all types of tests and other properties are instrument-dependent or not. Once the correlation between objective and sensory data has been established, focus will be given to development of a reproducible standard method.

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